Claims

1. A discharge apparatus, comprising an antenna element having a configuration in which a first and a second straight conductor with the same length are placed in parallel and are electrically connected each other at the one end to have a grounded end at other end of the first straight conductor and a power feeding end of alternating current power at the other end of the second straight conductor, a plurality of said antenna elements arranged to form an array antenna in such a way that the first and the second straight conductor are alternately placed in parallel at regular intervals on a first plane in a vacuum to generate a discharge plasma in the vacuum by feeding the alternating current power to said array antenna,

wherein the alternating current electric powers with the same excitation frequency and the phase shift of 180 degrees between adjacent power feeding ends are fed to said power feeding ends simultaneously, the excitation frequency of the alternating current power is 10 MHz – 2 GHz, and the length of said conductors is set so that the measured ratio of reflected wave to incident wave is 0.1 or less at the power feeding end.

2. A discharge apparatus, comprising an antenna element having a configuration in which a first and a second straight conductor with the same length are placed in parallel and are electrically connected each other at the one end to have a grounded end at the other end of the first straight conductor and a power feeding end of alternating current power at the other end of the second straight conductor, a plurality of said antenna elements arranged to form an array antenna in such a way that the first and the second conductor are alternately placed in parallel at regular intervals on a first plane in a vacuum to generate a discharge plasma in the vacuum by feeding the alternating current power to said array antenna,

wherein the alternating current electric powers with the same excitation frequency and the phase shift of 180 degrees between adjacent power feeding ends are fed to said power feeding ends simultaneously, the excitation frequency of the alternating current power is 10 MHz – 400 MHz, and the length La of said straight conductors is set to hold the inequality:

$$0.5(1/\alpha) < La < 10\ (1/\alpha)$$

in which a attenuation coefficient α (1/m) is expressed by:

$$\alpha = -\mathrm{Im}\left[6.28f\sqrt{\frac{1.26\times10^{-6}\ln\left(\dfrac{\delta}{3\times10^{-3}}\right)}{9.57\times10^{10}+\dfrac{1.13\times10^{11}}{\kappa_p}\ln\left(\dfrac{\delta}{7\times10^{-3}}\right)}}\right]$$

using a dielectric constant κ_p of plasma as a function of an excitation frequency f and a discharge pressure p (Pa), expressed by:

$$\kappa_p = 1-\frac{\dfrac{1.61\times10^{17}}{f^2}}{1-j1.54\left(\dfrac{p}{f}\right)\times10^{7}}$$

and a skin depth δ (m) of the electromagnetic field penetrating into the plasma, expressed by:

$$\delta = -2.10f\times10^{-8}\,\mathrm{Im}\left[\sqrt{\kappa_p}\right]$$

3.The discharge apparatus according to claim 1, wherein said straight conductor has a diameter of 10mm or less.

4.The discharge apparatus according to claim 2, wherein said straight conductor has a diameter of 10mm or less.

5.The discharge apparatus according to claim 3, wherein said straight conductor has a diameter of 1mm or more.

6. The discharge apparatus according to claim 4, wherein said straight conductor has a diameter of 1mm or more.

7. The discharge apparatus according to claim 1, wherein the diameter of said straight conductor is varied in the longitudinal direction.

8. The discharge apparatus according to claim 2, wherein the diameter of said straight conductor is varied in the longitudinal direction.

9. The discharge apparatus according to claim 7, wherein said straight conductor has a diameter of 10mm or less partially or entirely.

10. The discharge apparatus according to claim 8, wherein said straight conductor has a diameter of 10mm or less partially or entirely.

11. The discharge apparatus according to claim 1, wherein said straight conductor is covered partially or entirely with a dielectric.

12. The discharge apparatus according to claim 2, wherein said straight conductor is covered partially or entirely with a dielectric.

13. The discharge apparatus according to claim 11, wherein the thickness of said dielectric is varied in the longitudinal direction of said straight conductor.

14. The discharge apparatus according to claim 12, wherein the thickness of said dielectric is varied in the longitudinal direction of said straight conductor.

15. The discharge apparatus according to claim 13, wherein the edge of said dielectric is tapered in the cross section.

16. The discharge apparatus according to claim 14, wherein the edge of said dielectric is tapered in the cross section.

17. The discharge apparatus according to claim 11, wherein said dielectric is formed spirally about the longitudinal direction of said straight conductor.

18. The discharge apparatus according to claim 12, wherein said dielectric is formed spirally about the longitudinal direction of said straight conductor.

19. The discharge apparatus according to claim 1, wherein substrate bodies are placed on a second and a third plane which is located at respective sides of said first plane to simultaneously process both the substrate bodies placed on the second and the third plane.

20. The discharge apparatus according to claim 2, wherein substrate bodies are placed on a second and a third plane which is located at respective sides of said first plane to simultaneously process both the substrate bodies placed on the second and the third plane.

21. The discharge apparatus according to claim 19, wherein a plurality of said array antennas are arranged in one vacuum chamber.

22. The discharge apparatus according to claim 20, wherein a plurality of said array antennas are arranged in one vacuum chamber.

23. A plasma processing method, comprising;

arranging a plurality of antenna elements, each having a configuration in which a first and a second straight conductor with the same length are placed in parallel and are electrically connected each other at the one end to have a grounded end at the other end of the first straight conductor and a power feeding end of alternating current power at the other end of the second straight conductor to form an array antenna in such a way that the first and the second conductor are alternately placed in parallel at regular intervals on a first plane in a vacuum, and

feeding the alternating current power to said array antenna to generate a discharge plasma in the vacuum,

wherein the alternating current electric powers with the same excitation frequency and the phase shift of 180 degrees between adjacent power feeding ends are fed to said power feeding ends simultaneously, the excitation frequency of the alternating current power is 10 MHz – 2 GHz, and the length of said conductors is set so that the measured ratio of reflected wave to incident wave is 0.1 or less at the power feeding end.

24. A plasma processing method, comprising;

arranging a plurality of antenna elements, each having a configuration in which a first and a second straight conductor with the same length are placed in parallel and are electrically connected each other at the one end to have a grounded end at the other end of the first straight conductor and a power feeding end of alternating current power at the other end of the second straight conductor to form an array antenna in such a way that the first and the second conductors are alternately placed in parallel at regular intervals on a first plane in a vacuum, and

feeding the alternating current power to said array antenna to generate a discharge plasma in the vacuum,

wherein the alternating current electric powers of the same excitation frequency and the phase shift of 180 degrees between adjacent power feeding ends are fed to said power feeding ends simultaneously, the excitation frequency of the alternating current power is 10 MHz - 400 MHz, and the length La of said straight conductors is set to hold the inequality;

$$0.5(1/\alpha) < La < 10\,(1/\alpha)$$

in which a attenuation coefficient α (1/m) is given by:

$$\alpha = -\mathrm{Im}\left[6.28f\sqrt{\frac{1.26\times10^{-6}\ln\left(\frac{\delta}{3\times10^{-3}}\right)}{9.57\times10^{10}+\frac{1.13\times10^{11}}{\kappa_p}\ln\left(\frac{\delta}{7\times10^{-3}}\right)}}\right]$$

using a dielectric constant κp of plasma as a function of an excitation frequency f and a discharge pressure p (Pa), expressed by]

$$\kappa_p = 1-\frac{\frac{1.61\times10^{17}}{f^2}}{1-j1.54\left(\frac{p}{f}\right)\times10^{7}}$$

and a skin depth δ (m) of the electromagnetic field penetrating into the plasma, expressed by:

$$\delta = -2.10f\times10^{-8}\,\mathrm{Im}\left[\sqrt{\kappa_p}\right]$$

25. A solar cell, composed of a semiconductor thin film including Si element formed using plasma CVD method, said plasma CVD method comprising;

arranging a plurality of antenna elements, each having a configuration in which a first and a second straight conductor with the same length are placed in parallel and are electrically connected each other at the one end to have a grounded end at the other end of the first straight conductor and a power feeding end of alternating current power at the other end of the second straight conductor to form an array antenna in such a way that the first and the second conductor are alternately placed in parallel at regular intervals on a first plane in a vacuum, and

feeding the alternating current power to said array antenna to generate a discharge plasma in the vacuum,

wherein the alternating current electric powers with the same excitation frequency and the phase sift of 180 degrees between adjacent power feeding ends are fed to said power feeding ends simultaneously, the excitation frequency of the alternating current power is 10MHz - 2GHz, and the length of said conductors is set

so that the measured ratio of reflected wave to incident wave is 0.1 or less at the power feeding end.

26. A solar cell, composed of a semiconductor thin film including Si element formed using plasma CVD method, said plasma CVD method comprising;

arranging a plurality of antenna elements, each having a configuration in which a first and a second straight conductor with the same length are placed in parallel and are electrically connected each other at the one end to have a grounded end at the other end of the first straight conductor and a power feeding end of alternating current power at the other end of the second straight conductor to form an array antenna in such a way that the first and the second conductor are alternately placed in parallel at regular intervals on a first plane in a vacuum, and

feeding alternating current power to said array antenna to generate a discharge plasma in the vacuum,

wherein the alternating current electric powers of the same excitation frequency and the phase shift of 180 degrees between adjacent power feeding ends are fed to said power feeding ends simultaneously, the excitation frequency of the alternating current power is 10 MHz - 400 MHz, and the length La of said straight conductor is set to hold the inequality:

$$0.5(1/\alpha) < La < 10\,(1/\alpha)$$

in which a attenuation coefficient α (1/m) is given by:

$$\alpha = -\mathrm{Im}\left[6.28f\sqrt{\frac{1.26\times10^{-6}\ln\left(\dfrac{\delta}{3\times10^{-3}}\right)}{9.57\times10^{10}+\dfrac{1.13\times10^{11}}{\kappa_p}\ln\left(\dfrac{\delta}{7\times10^{-3}}\right)}}\right]$$

using a dielectric constant κp of plasma as a function of an excitation frequency f and a discharge pressure p (Pa), expressed by:

$$\kappa_p = 1-\frac{\dfrac{1.61\times10^{17}}{f^2}}{1-j1.54\left(\dfrac{p}{f}\right)\times10^{7}}$$

and a skin depth δ (m) of the electromagnetic field penetrating into the plasma, expressed by:

$$\delta = -2.10 f \times 10^{-8} \, \mathrm{Im}\left[\sqrt{\kappa_p}\right]$$